Simultaneous correction of motion and metal artifacts in head CT scanning

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I. Introduction

In a diagnostic CT scan, the presence of high density implants often induces artifacts, e.g. streaks and cupping, in the reconstructed images. Further problems arise if the patient moves during the scan. Even a slight movement can induce additional motion artifacts. The compound effects of the motion and metal degrade the image quality, and hence may affect the diagnosis.

Many efforts have been made to reduce the metal artifacts from implants [1] [2]. Similarly, methods for reducing rigid motion artifacts have been proposed by several groups [3] [4]. In this work, we study an approach which corrects the compound artifacts from metal implants and motion. Results are presented from simulations.

II. Methods

A. Iterative motion estimation with streaks reduction

The method in [4] assumes that the rigid pose of the object may be different for each projection view. Consequently, a rigid transform representing the object pose is estimated by a 3D-2D registration process for every view (motion update). Compensation for changes in pose during the scan is applied during reconstruction (image update). The motion-corrected image and the motion estimate are alternately updated to increase the likelihood (Fig. 1).

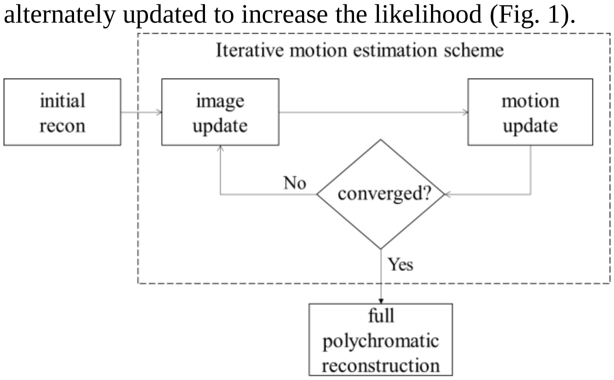

Fig. 1. Flow chart of the iterative motion estimation scheme.

The image update can be performed with any reconstruction algorithm that can model the arbitrary rigid motion. We have been using iterative algorithms. In [4], MLEM (Maximum Likelihood Expectation Maximization) was used for image updates, but here we adopted another patch-based iterative reconstruction approach. The idea of this approach is that a reconstruction update can be divided into updates on metal and no-metal patches. In different patches, different resolution models can be defined.

Specifically in each image update, an initial image is created using NMAR (Normalized Metal Artifacts Reduction) to suppress the metal artefacts and to define small patches containing the metals and a large patch containing the rest of the image. The iterative reconstruction starts from this image, and updates all patches were sequentially (metal patches first, then the background patch). Such patch-based sequential update is known to improve convergence, in particular for the smaller patches. For example, in the update equation of monochromatic MLTR (Maximum Likelihood Transmission Reconstruction) (Eq. 1), the denominator of the update steps will be smaller when the area of the update patch is smaller:

$$\mu_j^{new} = \mu_j + \frac{a_j \sum_i c_{ij}(\bar{y}_i - y_i)}{\sum_i c_{ij}(\sum_k c_{ik} a_k)\bar{y}_i} \tag{1}$$

where

$$\begin{cases} a_j = 1 \text{ if } j \in \text{patch} \\ a_j = 0 \text{ if } j \notin \text{patch} \end{cases}$$

i is the index of the projection lines, y_i is the measured transmission scan, $\bar{y}_i$ is the estimated transmission scan, computed from the current reconstructed image $\mu = \{\mu_j\}$, with μ_j the linear attenuation coefficient in voxel j. c_{ij} is the intersection length of projection line i with voxel j

It has been shown that patched MLTR has the capability to significantly reduce streaks artifacts by improving the convergence near the metals [2]. In addition, the improved reconstruction of the metals should result in improved motion estimation, since the metals contribute high contrast details to the projections which should benefit the 3D-2D registration.

The final image produced by the joint motion estimation and image reconstruction, is used as the initial image for the final, full polychromatic reconstruction (Fig. 1).

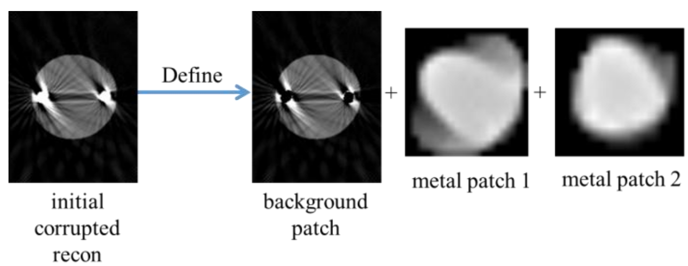

Fig. 2 Patch definition. Metal patches were identified by dilation after thresholding on an initial reconstruction which was performed from the measured projections. The pixel size in the metal patches was two times smaller than that of the non-metal patch.

B. Reconstruction with estimated motion and known energy model

The iterative motion estimation generates estimates of the motion and the motion-corrected image with preliminary metal artifacts correction. Using these estimates, a polychromatic reconstruction algorithm performs simultaneous motion and metal artifacts reduction. To model the energy model in that polychromatic reconstruction, we used the hybrid reconstruction approach proposed in [2]. In the metal patches, a full polychromatic model was used (IMPACT-iterative maximum likelihood polychromatic algorithm for CT) reconstruction. For the non-metal patch, a version of MLTR was applied which implements the so-called water-correction (MLTRC). One IMPACT update requires 4 forward and

4 back projection operations, while one MLTRC update contains 1 forward and 2 back projection operations. Since the IMPACT calculations are restricted to the small metal patches, the increase in processing time due to the polychromatic modeling is limited.

Motion correction was performed by incorporating the estimated motion into the system matrix, during every single forward and back projection operation [4].

III. Simulations and Results

A. Simulation setup

A 3D software phantom representing a water cylinder containing two metal (Fe) implants was designed. A helical scan with a Siemens Definition AS scanner (peak voltage 120kVp, angles per rotation 300, pitch 1.0, collimation 32×1.2 mm) was simulated. During this simulated acquisition, the object moved rigidly. The simulation and reconstruction were done with the same voxel size. The simulated spectrum and the phantom are shown in Fig. 3.

The iterative motion estimation algorithm of section II.A applied 11 iterations, each consisting of an image update and a motion update. For the image update, starting from a NMAR image, the patched MLTR algorithm applied 1 iteration with 30 subsets in alternate updates for metal and non-metal regions. The IMPACT and MLTRC in II-B started from a NMAR image, applied 2 iteration, 30 subsets.

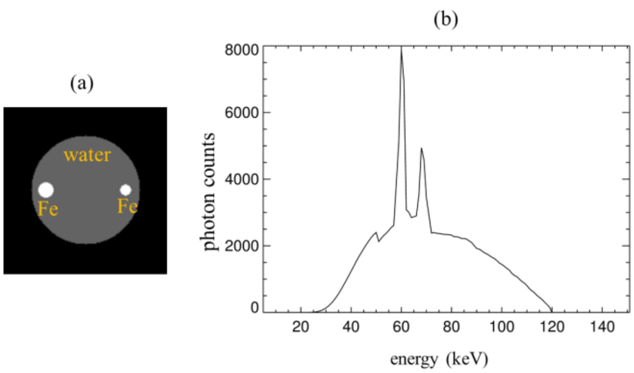

Fig. 3 (a) digital phantom (image size $160\times160\times30$, voxel size $1\times1\times1$ mm^3). (b) simulated spectrum at 120kVp from Specktr [5].

B. Experiments

From the simulated motion corrupted projections, we computed four reconstructed images with different correction strategies, and therefore obtained the following five images:

1) **REF:** The digital phantom was used as the reference image.
2) **FDK (no correction):** A Feldkamp-Davis-Kress reconstruction was performed for the simulated projections, without motion and without beam hardening correction.
3) **MC (only motion correction):** Motion was estimated in an iterative scheme and corrected in patched MLTR reconstruction (II-A). After that, a monochromatic MLTR reconstruction was performed.
4) **POLY (only metal artifact correction):** Only polychromatic reconstruction were performed (II-B). No motion was estimated beforehand nor corrected in this reconstruction.
5) **MC + POLY (both corrections):** Motion was first estimated (II-A) and then corrected inside a polychromatic reconstruction (II-B).

C. Results

To compare the results from different experiments, we selected a middle plane of all images to display in Fig. 4. The reconstruction that both modeled the estimated motion and X-ray spectrum has the least artifacts and is closest to the reference image in appearance. Selected parameters of the estimated motion from Experiment 5) are plotted in Fig. 5, together with the known simulated motion.

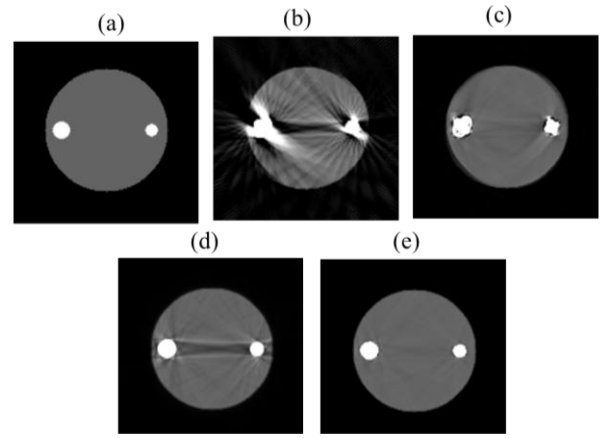

Fig. 4. Results from experiments: (a) reference image; (b) FDK with no correction; (c) correction for metal artifacts only; (d) correction for motion artifacts only; (e) correction for motion and metal artifacts.

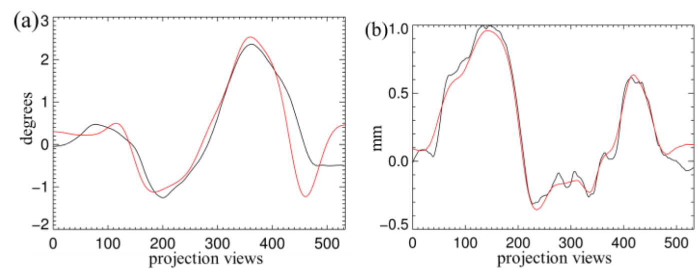

Fig. 5 Motion in two selected degrees of freedom as a function of the projection view number: (a) rotation around the rotation axis of the x-ray source; (b) translation along the rotation axis. Estimated motion is in black, and the true simulated motion is in red. The other four parameters are not shown due to the limited space.

IV. Discussion and Conclusion

The combination of rigid head motion and the presence of metals can severely degrade the image quality in CT imaging, preventing accurate diagnosis. In this study, we investigated an approach to correct for artifacts due to the combined effects of both factors. Patch-based reconstruction was introduced to an iterative motion estimation scheme, which estimated the motion and removed the streaks at the same time. A polychromatic reconstruction was performed to account for both energy and motion. The corrected image was superior to the reconstruction with motion correction only or with metal artifacts reduction only. The evaluation of the performance of the algorithm in patient studies is ongoing.

References

[1] E. Meyer et.al. (2010), *Med. Phys.*, 37, p. 5462-93
[2] K. V. Slambrouck et.al. (2012), *Med. Phys.*, 39, p. 7080-93
[3] H. Yu et.al. (2007), *IEEE TMI*, 26, p. 249-260.
[4] T. Sun et.al. (2016), *Med. Phys.*, 43, p. 5705-16.
[5] Punnoose et.al. (2016), *Med. Phys.*, 43, p. 4711-17.